REPORT TO THE CONGRESS

BY THE COMPTROLLER GENERAL OF THE UNITED STATES

Status Of The NAVSTAR Global Positioning System

Department of Defense

The NAVSTAR Global Positioning System is being developed to provide worldwide navigational data for military users.

The program is in early development with full operational capability now planned for 1983.

This report presents GAO's views of the current status of the Global Positioning System program with regard to cost, schedule, and performance. It contains recommendations to the Secretary of Defense concerning establishing performance requirements, testing of the system, complete costing of the program, and including the program in the Selected Acquisition Reporting System.

PSAD-77-33

COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

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To the President of the Senate and the
Speaker of the House of Representatives

This report presents our views on the major issues of the NAVSTAR Global Positioning System which will require attention. A draft of this report was reviewed by agency officials associated with the program and their comments are incorporated as appropriate.

For the past several years we have annually reported to the Congress on the status of selected major weapons systems. This report is one of a series of 29 reports that we are furnishing this year to the Congress for its use in reviewing fiscal year 1978 requests for funds.

We made our review pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), and the Accounting and Auditing Act of 1950 (31 U.S.C. 67).

We are sending copies of this report to the Director, Office of Management and Budget, and the Secretary of Defense.

ACTING Comptroller General
of the United States

COMPTROLLER GENERAL'S
REPORT TO THE CONGRESS

STATUS OF THE NAVSTAR GLOBAL
POSITIONING SYSTEM
Department of Defense

D I G E S T

The NAVSTAR Global Positioning System is a satellite-based radio navigation system. Its performance is predicted to be much better than existing navigation systems. The Global Positioning System will consist of 24 satellites, ground control equipment, and user equipment designed for a variety of Air Force, Army, Navy, and Marine Corps applications. All services are participating in the program with the Air Force acting as the management executive. Initial operational capability is planned for December 1983. Testing to demonstrate system performance capabilities is scheduled to begin in 1977 and is to be completed by mid-1978.

GAO's review included evaluations of system performance and testing, program schedule, and program cost. The following matters were noted during the review.

--Performance requirements relating to specific users' needs have not been established, but certain performance goals were set by the program office. (See p. 12.)

--Development problems with user equipment and satellites caused a schedule delay of almost a year in the current phase. (See p. 19.)

--By compressing the testing from 22 to 14 months program officials expect to limit the schedule slippage for the current phase to 2 or 3 months. (See p. 21.)

--The revised test schedule is optimistic in that it provides no leeway for unforeseeable problems. (See p. 21.)

--Test plans specificy neither the minimum amount of testing to be performed nor criteria for gauging successful performance. (See p. 16.)

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--The Air Force plans to accelerate development of user equipment in subsequent phases. (See p. 21.)

--Estimated cost for the initial phase of the program has significantly increased due primarily to additions to support a Navy program. Technical problems and higher acquisition costs for satellites also contributed. (See pp. 26 and 27.)

--Total reported program cost is over $1.3 billion. This amount, however, does not include cost for user equipment or for replenishment satellites. (See p. 29.)

--The program cost estimate does not reflect Army or Navy participation in phase II of the program. Many activities related to the system and their costs are also not included in program documents. GAO believes the total program will actually cost in excess of $3 billion. (See pp. 28 and 29.)

Testing to evaluate the results of Global Positioning System development will begin shortly. Approval of further development and the committment by the Navy and the Army to use the Global Positioning System will be based, in large part, on the testing results. GAO is concerned that formal system performance requirements were not approved and used as a basis for the testing program and that criteria for evaluating the results of development, to date, were not established. The compressed testing period and the desire to accelerate fielding the operational Global Positioning System could, in our opinion, exert undesirable pressures on the scope of testing and on the acceptance of higher risks associated with concurrency.

Although the Global Positioning System is still in early development, program cost estimates show large increases. The full cost of the Global Positioning System, including related activities, is difficult to determine. GAO believes complete cost information should be available to those evaluating and making decisions about the Global Positioning System program.

GAO recommends that the Secretary of Defense

--review the Global Positioning System program to determine operational system performance required by the Air Force, Army, Navy, and Marine Corps,

--establish testing criteria for evaluating the adequacy of the Global Positioning System development progress and the readiness of the Global Positioning System to proceed into the next development phase,

--assess the time allotted for the Global Positioning System phase I test program relative to the scope of testing needed to demonstrate Global Positioning System development progress,

--explore alternatives to the planned solicitation of contractor proposals before testing, as a means of accelerating Global Positioning System operational capability,

--determine the total cost for the Global Positioning System development and related activities and the total estimated cost to provide a Global Positioning System operational capability for all the military services, and

--assure Global Positioning System program visibility by including it in the Selected Acquisition Reporting System.

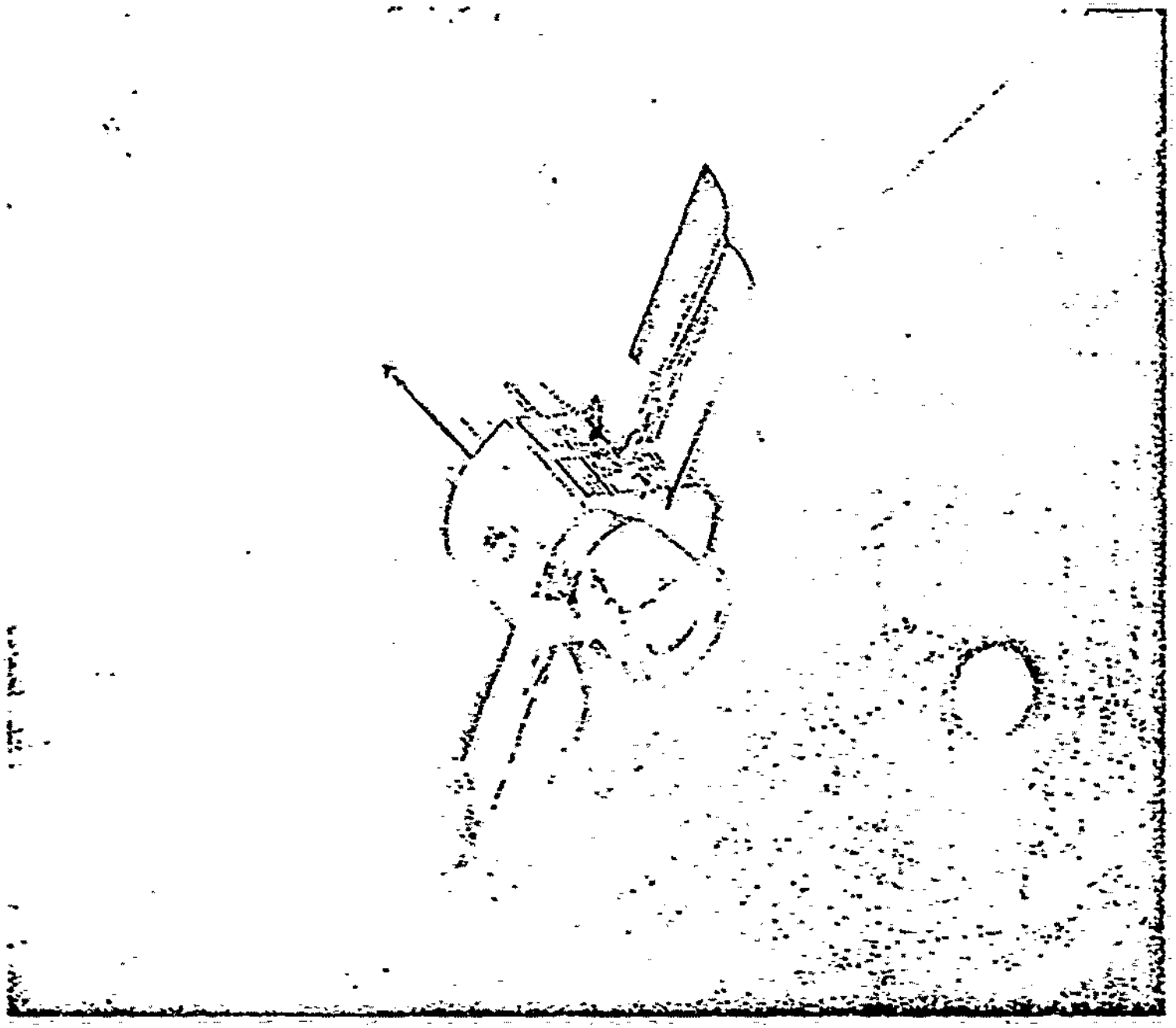
A draft of this report was reviewed by agency officials and their comments were incorporated as appropriate.

Tear Sheet

Contents

ABBREVIATIONS

GAO	General Accounting Office
GPS	Global Positioning System
NDS	Navigation Development Satellite
NTS	Navigation Technology Satellite



NAVSTAR SATELLITE

CHAPTER 1

INTRODUCTION

Since the early 1960s the Navy and the Air Force have pursued the development of navigation and position location systems using radio signals transmitted from space vehicles. Both services conducted programs to demonstrate the feasibility of navigation satellite systems. The Navy sponsored two programs: Transit, now operational, and Timation, a technology program to advance high-stability oscillators (time standards), time transfer, and two-dimensional navigation, (i.e., longitude and latitude). The Air Force concurrently conducted preliminary concept formulation and system design studies for a three-dimensional (i.e., longitude, latitude, and altitude) navigation system called System 621B.

Navy and Air Force efforts to achieve satellite navigation were integrated following a memorandum issued by the Deputy Secretary of Defense on April 17, 1973. The memorandum designated the Air Force as the executive service to prepare plans for a comprehensive system based on aspects of the Navy's Timation program and the Air Force's 621B program. A system concept designated Navstar Global Positioning System (GPS) emerged in Development Concept Paper 133, dated November 26, 1973. The GPS program was briefed to the Defense Systems Acquisition Review Council. On December 22, 1973, the Deputy Secretary of Defense approved initiation of the GPS program.

SYSTEM DESCRIPTION

GPS is a space-based radio navigation system designed to provide users with worldwide three-dimensional position and velocity information. GPS consists of three segments (1) a space segment, satellites that transmit radio signals, (2) a control segment, ground-based equipment to monitor the satellites and update their signals, and (3) a user equipment segment, devices to receive and convert satellite signals into user position information. Descriptions of the three segments in the planned GPS operational configuration are presented below.

Space segment

The space segment consists of 24 satellites, 8 each in 3 planes, with circular, 10,900 nautical mile orbits.

(See fig. 1.) The satellites continuously broadcast on two radio frequencies, providing satellite identification and navigation data to be processed by the GPS users' receivers. The user's position and velocity is established by determining its distance from the known position of several GPS satellites.

The GPS satellite, shown in figure 2, has a design life of 5 years, but it carries battery power and repositioning fuel to last 7 years. Electrical power is supplied by two solar energy converting panels that continually track the sun and by three batteries for use when the earth eclipses the sun. Each GPS satellite has an onboard propulsion system for maintaining orbit position and for stability control.

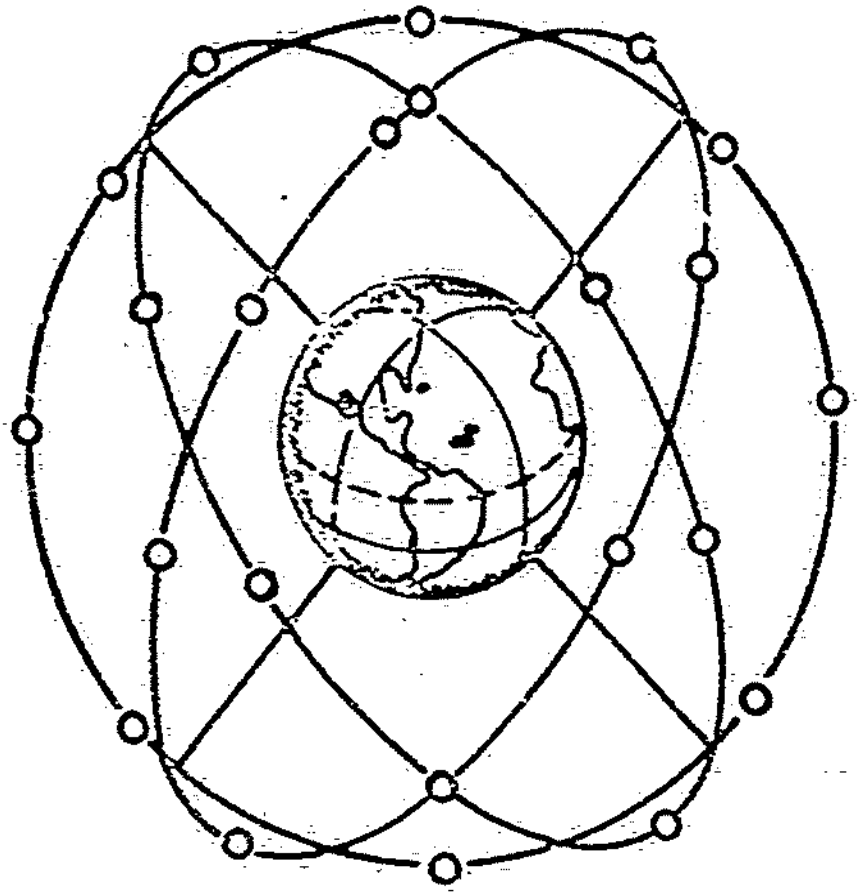
Control segment

The operational control segment consists of five monitor sets, a master control station, and an upload station. The monitor sets are to be widely spaced on United States controlled territory, and the master control and upload stations are to be collocated in the central continental United States.

Each monitor set consists of a user receiver to acquire satellite signals, a computer, and test and calibration equipment. The sets monitor satellite orbits and signal data, collect meteorological data, and transmit this information to the master control station.

The master control station processes the information received from the monitor sets to determine satellite position and signal data accuracy. The master control station produces messages to correct for discrepancies in satellite position and signal data errors and relays the message to the upload station.

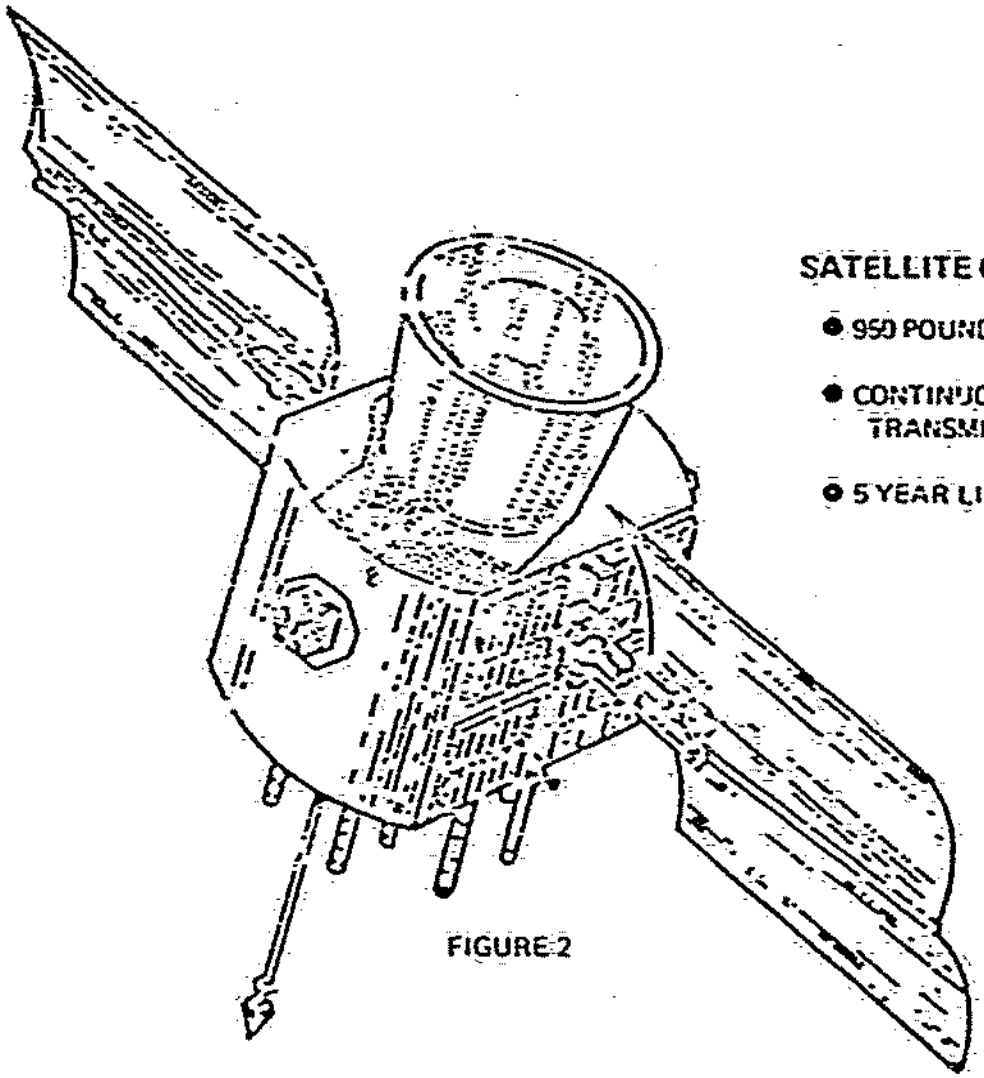
The upload station has a transmitter for relaying information to the satellites. Information may be of the type mentioned above or it may be instructions for altering or encrypting satellite radio signals. Signal alteration could be used to degrade the system's performance to all but specifically authorized users by denying GPS access for precise position location.



ORBITAL CONFIGURATION

- 24 SATELLITES
- 3 CIRCULAR ORBITS
- 12 HOUR PERIODS

FIGURE 1



SATELLITE CONFIGURATION

- 950 POUNDS
- CONTINUOUS SIGNAL TRANSMISSION
- 5 YEAR LIFE EXPECTANCY

FIGURE 2

User equipment segment

The user equipment segment includes several different types of user equipment planned to satisfy the different requirements of various military users. Potential users were identified during GPS studies and were categorized in six classes based on operational requirements; i.e., some users require more precise navigation data and/or operate in more stringent dynamic environments than do others. Examples of user applications (classes) are strategic and attack aircraft, ships, submarines, armored vehicles, and ground troops. Current projections of total user equipment needs within the Department of Defense exceed 27,000 units.

User equipment configurations have been defined for the concept validation phase only, and designs are subject to refinement based on developmental test and evaluation and further user inputs.

In general, user sets will have an antenna, receiver, data processor with software, a crystal oscillator (clock), and a control display unit. Some sets are to be integrated with auxiliary sensors, such as inertial navigation units, to enhance system performance. Depending on user needs, the equipment is designed to receive and process data from four satellites on either a simultaneous or sequential basis. The equipment measures the user's velocity and range with respect to each satellite. The user set then processes this data in earth-centered coordinates to derive the user's three-dimensional position and velocity. Positioning data is presented on a display unit in geographic coordinates, military grid coordinates, or any other coordinate system desired by the user.

PROGRAM DESCRIPTION

The GPS program is divided into three phases: Concept Validation (phase I), System Validation (phase II), and Production (phase III). The operational GPS described previously is planned to evolve from these phases as each phase builds and expands on the previous phase.

Phase I, Concept Validation, is the currently approved GPS program. This phase has a planned completion date of May 1978. Phase II, System Validation, is planned to run

through the end of 1981, at which time phase III, Production, is to begin. Because phase I is the only approved phase and testing has not yet begun, planning and related information for phases II and III is tentative and limited. Activities planned for each phase follows.

Phase I, Concept Validation

Phase I is intended to be a minimum-cost validation of the GPS concept. The test program is to include demonstrating the military value of the system.

The phase I space segment consists of six satellites, three each in two orbit planes. This constellation is designed to provide periodic (up to 4 hours a day), three-dimensional coverage over selected test areas in the western United States and to provide support to the Navy's Fleet Ballistic Missile Improved Accuracy Program. The first satellite to be deployed will be the Navigation Technology Satellite (NTS-2) developed and fabricated by the Naval Research Laboratory. It will be used to investigate satellite survivability with respect to space radiation hazards and to determine the space stability of atomic clocks. The Naval Research Laboratory was responsible for the initial research and development effort to space-qualify advanced atomic clocks for possible use in GPS. Its past efforts included verifying the accuracies of space-based atomic clocks aboard NTS-1, the last satellite in the Navy's Timation series.

The remaining phase I satellites are called Navigation Development Satellites (NDS) to be developed and built by Rockwell International Corporation, Space Division, Seal Beach, California. Rockwell is under contract to build eight spacecraft, with NDS-1 through 5 to be used in the initial phase I network and NDS-6 through 8 to serve primarily as replenishment vehicles to the first six spacecraft.

Phases I and II satellites will be launched from Vandenburg Air Force Base, California, using refurbished Atlas F launch vehicles, acquired from existing Air Force inventories. The Atlas missile will be fitted with a solid-fueled motor upper stage, being developed for the GPS program by the Fairchild Corporation.

Supporting these satellites is the phase I control segment, developed and fabricated by the General Dynamics Corporation, Electronics Division, San Diego, California.

It consists of prototypes of the master control and upload stations and four monitor sets. This control segment will perform essentially the same functions, described earlier, as the operational system control segment.

The user equipment segment development contract was awarded to General Dynamics for the design, development, and fabrication of four types of equipment that ultimately may satisfy the requirements of the six classes of users. General Dynamics subcontracted user equipment development to Magnavox Company's Research Laboratory, Torrance, California. Magnavox had previous experience with Transit program receivers. The four types of user equipment are identified as X sets, Y sets, Z sets, and manpacks. Table 1 shows these sets, their planned performance capabilities, and potential military users.

TABLE 1

Phase I User Equipment

Equipment nomenclature	Performance capabilities	Potential users
X set	High accuracy High dynamic Simultaneous 4-channel reception	Tactical aircraft Missiles Submarines Aircraft carriers Helicopters
Y set	High accuracy Medium dynamic Sequential single-channel reception	Naval combat ships Refueling aircraft Helicopters
Z set (low cost)	Medium accuracy Medium dynamic	Naval support vessels Search and rescue and cargo aircraft
Manpack	Portable High accuracy Low dynamic	Ground troops Land vehicles

Contracts were also awarded to the Texas Instruments Corporation, Dallas, Texas, for development of user equipment primarily for competition and reducing risk through alternate design concepts. One contract is for a high-dynamic set comparable to the X set, and the other contract is for an alternate manpack set.

Another phase I user segment contract is being funded through the Air Force Avionics Laboratory. The Laboratory is evaluating antijam characteristics of GPS user equipment. The Laboratory contracted with Rockwell's Collins Radio Group to develop and fabricate a user set with antijamming characteristics.

During the remainder of phase I, all types of user equipment are to undergo initial field testing to evaluate the operational utility of GPS for military applications. These tests, in which all three phase I GPS segments will be utilized, are discussed in chapter 2.

Phase II, System Validation

In phase II the space segment will be increased to nine satellites, three each in three orbit planes. Current plans call for the procurement of 12 phase II satellites to achieve this configuration. They are to be essentially identical to the phase I satellites, with changes limited to those necessary to replace or modify unsuitable components or to incorporate improved equipment.

The control segment is to undergo major development during phase II. The operational master control station, upload station, and monitor set are to be developed and located in the central continental United States where they will assume the tasks performed by their phase I counterparts. The four phase I monitor sets are to be retrofitted with phase II equipment.

User equipment activities are to center on the development, fabrication, and testing of prototype user sets evolving from those tested in phase I. One exception, the low-cost Z set which is being prototyped in phase I, is to finish initial operational testing and will enter limited production. These Z sets are planned for installation in operational Air Force aircraft to take early advantage of GPS' worldwide two-dimensional capability planned for 1981.

Phase III, Production

Current plans are to procure 20 satellites during phase III to achieve the operational configuration of 24 satellites. Phase III satellite launches are planned to change from the expendable Atlas F launch vehicle to the Space Shuttle, where four GPS satellites can be deployed on one flight.

During phase III the control segment is to be upgraded to support the system's initial operational capability. The phase I prototype master control and upload station at Vandenberg Air Force Base are to be upgraded for use as backups to the operational stations. The monitor sets are to be retrofitted as necessary with operational equipment developed in phase III.

User equipment is planned to enter full production during phase III. Quantities and types of equipment are to be based on user requirements and funded by the individual users. Operational testing is planned to continue during phase III to verify the operational effectiveness of the GPS and to obtain additional information concerning the use of all types of user equipment for new or improved applications and tactics.

Initial operational capability, with an 18-satellite configuration, is scheduled for 1983. Full operational capability, with a 24-satellite configuration, is scheduled for 1984.

PROGRAM MANAGEMENT

On April 17, 1973, the Air Force was designated as the executive service for the GPS joint service program by the Deputy Secretary of Defense. The Air Force Systems Command is the implementing command for phase I concept validation activities covering the development and testing of the space, control, and user equipment segments. Management of the GPS program is performed through the Joint Program Office at the Space and Missile Systems Organization, El Segundo, California.

The Program Manager was delegated authority as the single manager to plan, organize, coordinate, control, and direct the GPS program. Within the Joint Program Office, the Program Manager is supported by Deputy Program Managers from the Air Force, Navy, Army, Marine Corps, and the Defense Mapping Agency who serve as representatives of their respective organizations.

Management organization

Manning of the program office is drawn from the Air Force and from each service or agency having an assigned Deputy Program Manager. Other personnel, both military and civilian, are assigned to functional areas in the program office. These specialists are functionally

responsible to the appropriate functional director but report administratively to their respective Deputy Program Manager. This organization allows other service or agency personnel to be fully integrated into the Joint Program Office and to influence the development decisions with respect to their own service or agency requirements.

RELATIONSHIP TO OTHER SYSTEMS AND PROGRAMS

If the GPS operates as planned, it could replace or enhance many current positioning systems. Additionally, the GPS capability may be used to support strategic and tactical systems.

Systems which GPS could replace or enhance

Examples of some of the systems GPS could replace for both aircraft and ship applications are Loran, Omega, and Tacan. The Air Force has plans, pending successful phase I testing of the Z set, to procure 1,032 Z-type user receivers in phase II to replace Tacan units in some of its operational aircraft. Blind bombing and specialized instrument landing systems could also be enhanced by integration with GPS receivers. The Navy's Transit satellite positioning system which now provides two-dimensional navigation data is also expected to be replaced by GPS.

Integration and compatibility of the GPS with existing systems is to be formally addressed during phase II for such systems as the Tactical Loran System, the Lightweight Doppler Navigation System, and the Digital Avionics Information System. However, some efforts, such as compatibility and interface studies, between GPS and these systems have already been made. Analysis of the issues related to integration of the GPS with the Precise Emitter Location Strike System and the Joint Tactical Information Distribution System have also been made.

The Defense Mapping Agency and the National Aeronautics and Space Administration have contracted with Magnavox, the phase I user equipment developer, for six unique GPS receivers to be integrated into their satellites. This effort is to determine the feasibility of tracking satellites using the GPS system, which would thereby reduce the need for ground tracking stations. This experiment is not a part of the approved GPS program, and the costs are not shown in program costs. (See p. 28.) However, it should provide an additonal test of GPS capability. Magnavox's

efforts in this regard are to proceed on a noninterference basis with its work on the primary GPS user equipment.

Systems and programs interfacing with GPS

A major relationship exists between GPS and the Navy's Strategic Systems Program Office which is responsible for the Submarine-launched Ballistic Missile Improved Accuracy Program. This relationship developed from a request by the Director of Defense Research and Engineering that phase I GPS provide precision missile tracking to support the Satellite Missile Tracking Program. The missile tracking program is to support the missile accuracy improvement program by identifying Trident and Poseidon missile guidance system errors. The Navy plans to use this information to determine potential accuracy improvements that can be used in future submarine-launched ballistic missile systems.

The Navy plans to modify and install six Magnavox X-type user sets on ships and tracking stations, deployed along either the Pacific or Atlantic missile test ranges. During periods of satellite availability, ballistic missiles are to be launched so that they will travel near the ships and stations. The missiles will be equipped with translators capable of retransmitting GPS satellite signals. As the missile passes near a ship, the missile's and the ship's positions will be continuously recorded. Through subsequent analysis of the recorded data, the Navy hopes to measure and isolate errors in missile guidance systems. Funding relationships between the programs are explained in chapter 4. (See p. 27.)

Several programs would like to put their equipment into the GPS satellites to take advantage of the satellites' planned worldwide coverage. Rockwell International is developing two systems which are designed to provide GPS satellites with the capability to perform secondary missions. One of these systems is designed to detect, locate, and measure nuclear detonations, and the other is a worldwide communications package. Both are in the early stages of development and are proceeding on a noninterference basis with GPS activities. These programs and their related costs are not part of the approved GPS program.

CHAPTER 2

NAVSTAR GPS PERFORMANCE STATUS, PHASE I, CONCEPT VALIDATION

Concepts are to be validated in phase I for a high-accuracy, worldwide, three-dimensional positioning system, based on radio signals from satellites. Estimates of expected future GPS performance have been prepared. However, neither the performance to justify further development nor the required operational system performance has been defined. Major development problems occurred in two GPS segments, but program officials believe these and lesser problems have been satisfactorily resolved. At the present time, segment development testing is not complete and system testing has not begun. Consequently, data as to actual performance of GPS is not available.

PERFORMANCE REQUIREMENTS

The overall objective of phase I is to validate the GPS concept that a space-based navigation system can provide highly accurate position and velocity information to suitably equipped users located anywhere on or near the earth. For the most part, specific performance requirements have not been established, according to program officials, because the system is considered to provide orders of magnitude improvements over other navigation systems. The program is currently addressing requirements specified in the Air Force's Military Airlift Command Required Operational Capability document for a navigation system. Specific requirements for GPS are in the approval process.

All military services are interested in using GPS. Because each service has peculiar requirements for GPS, each service identified certain testing objectives as being of paramount importance. After GPS has demonstrated its capabilities, the services are to decide whether GPS can satisfy their particular requirements for a navigation system.

In addition to service objectives, the GPS program office was tasked to meet other technical and operational objectives in satisfying program goals. Examples of some of the demonstrations planned during phase I are precision weapon delivery, terminal navigation and larding, operation

in a jamming environment, Navy ship operations, and Army land and helicopter operations.

PREDICTED PERFORMANCE

Although specific performance requirements have not been established, the GPS program office developed performance goals for GPS user equipment for each of the program's three phases. These goals, shown in table 2 are subject to design-to-cost trade-offs and other considerations based on the results of system testing. Except for the Z set which is being prototyped in phase I, phase I user equipment configurations are expected to change considerably before production.

TABLE 2

Predicted Performance Parameters for User Equipment by Program Phase

Performance Characteristics by type of user equipment	Program phase I	Program phase II	Program phase III
Ranging error (meters):			
X and Y sets	6 to 9	5 to 8	4 to 7
Z set	15 to 20	15 to 20	15 to 20
Manpack	18 to 25	10	3
Velocity error (knots):			
X and Y sets	.1	.08	.05
Z set	.5	.4	.2
Manpack	(a)	(a)	(a)
Timing error:			
X and Y sets (nanoseconds)	18 to 25	15 to 25	12 to 21
Z set (nanoseconds)	45 to 60	45 to 60	45 to 60
Manpack (seconds)	1	1	1
Time to first fix (seconds):			
X and Y sets	80 to 180	80 to 180	80 to 180
Z set	200 to 300	200 to 300	200 to 300
Manpack	240	300	300
Meantime between failure (hours):			
X and Y sets	500	b/TBD	1200
Z set	500	500	1200
Manpack	500	1000	2000
Size (cubic meters):			
X and Y sets	.2	TBD	TBD
Z set	.11	.11	TBD
Manpack	.018	.02	.01
Weight (kilograms):			
X and Y sets	100.0	TBD	TBD
Z set	22.5	22.5	TBD
Manpack	10.5	9.1	3.6 - 5.5

a/No requirement.

b/To be determined.

An important point about the predicted parameters shown in table 2 is that they are based on the operational conditions expected to be encountered by the users of each type of equipment. (See table 1, p. 6.) For instance, in phase III, the manpack has a higher predicted accuracy than the more sophisticated X and Y sets because manpack users are virtually stationary, compared to the highly dynamic users of X sets.

Table 2 also shows identical predicted performance for X and Y sets, whereas table 1 shows the high dynamic X set has a simultaneous processing four-channel capability and the medium dynamic Y set has a less sophisticated, sequential processing single-channel capability. An issue to be addressed during phase I testing is the difference, if any, between X and Y set capabilities. The less complex and less costly Y set may prove to be adequate for some of the users now planned to receive X sets.

TESTING

To date, testing generally has been limited to factory-level checkout and design verification tests made by the contractors on their respective segments; i.e., space, control, and user equipment. A few laboratory tests have been made to evaluate the compatibility of the X set receiver and the GPS satellite transmitter designs.

Tests involving field demonstrations of the phase I GPS segments in combination in an operational environment are planned to begin in mid-1977. Although these tests are designed primarily for the evaluation of user equipment, they are also viewed as demonstrations of space and ground control equipment performance as well. Detailed plans for phase II and phase III testing have not been formulated. Phase I testing for each GPS segment follows.

Satellite testing

Satellite testing has been limited to design verification tests. A final determination of each satellite's performance can be made only after the satellite has been placed in orbit and activated. Program officials have stated that to minimize the chances of satellite failure, the contractor is following stringent design and checkout procedures.

Control and user equipment testing

The testing of control and user equipment is discussed together because the X user set is an integral component of the control equipment and is considered the highest risk item in the control segment. With limited exceptions, control equipment performance does not require new or untested technology.

Like the satellites, user equipment testing has been limited to factory-level checkout and design verification tests. To date, no user equipment field demonstrations have been conducted in the GPS program. The program office plans to begin a series of user equipment tests a few weeks after the first phase I satellite is launched.

A test range has been constructed for GPS user equipment field demonstrations at the U.S. Army Proving Grounds near Yuma, Arizona. The range is a ground-based system of four simulated satellite transmitters. To an aircraft equipped with a user set, the range provides an upside down, or inverted simulation of the GPS. The range is an early means of evaluating user equipment performance since availability of a set of four satellites is not expected until several months after initial user equipment delivery.

As the phase I satellites become operational, user equipment testing is to utilize the satellites, when they are available, or, at times, utilize a hybrid combination of satellite and ground transmitter signals. The range also provides a testing capability during periods when phase I satellites are not visible over the Yuma range, about 20 to 22 hours daily.

As user equipment is delivered, it is to be installed in a variety of vehicles for initial testing on the range. Program officials plan, after a four-satellite constellation is achieved, to accumulate sufficient quantitative test data so that user equipment accuracy and performance capabilities can be assessed. Plans then call for a series of demonstrations of the military value of GPS.

The phase I Field Test plan for GPS user equipment presents an orderly approach for the demonstration of the GPS concept. The plan calls for tests that realistically approximate the operational environments expected to be encountered by all military users, specifies that test results are to be fully documented, and entails active

involvement of user service representatives in conducting tests.

A potential weakness of the test plan is that the minimum number of tests to be made and the degree of accomplishment needed to validate the GPS concept are not specifically stated. Program officials told us that future supplements to the field test plan would contain a maximum number of tests to be made and that, if initial test results are better than expected, the number of tests would be reduced. The GPS Program Manager has the authority to vary the number of tests to maintain emphasis on the highest priority items. Although such flexibility may be desirable, it can also lead to trade-offs between the scope of testing and schedule consideration. (See p. 21.)

PROBLEMS ENCOUNTERED DURING SUBSYSTEM DEVELOPMENT

According to program officials, the major technical problems experienced as of December 1, 1976, were in development of the X set user equipment and the GPS satellite signal transmitter.

Based on positive results from preliminary factory tests and analyses, program officials believe technical problems in both of these items have been resolved. As discussed in chapter 3 (see p. 19), the X set and signal transmitter problems resulted in phase I schedule slippages.

There were other technical problems, but up to now their impact on the phase I schedule was overshadowed or masked by delays caused by the X set and satellite transmitter problems. Program officials believe any remaining problems will be resolved in time to prevent further schedule slippage. Initial factory qualification testing provided confidence that adequate solutions to all identified problems have been found.

THREATS TO GPS

Threats to GPS fall into two broad categories: (1) physical negation of the satellite or control segment

and (2) nonlethal degradation of system performance through electronic countermeasures.

The most likely scenario in which the entire GPS would be physically negated seems to be a high level of conflict in which nuclear weapons would be used to destroy a number of satellites or the control segment. However, because of the large number of satellites and their wide spacing in the planned operational satellite constellation, a major effort would be required to negate total system capability. Any attack against the satellites would be easy to detect and expensive for the enemy. Similarly, physical negation of the control segment would require an attack on United States territory. Sabotage should be preventable through adequate security precautions.

Nonlethal degradation of the GPS would be the most cost effective and more likely approach that might be attempted by an enemy in low levels of conflict. GPS has many features which tend to minimize some of its vulnerability to electronic countermeasures. Deception or "spoofing" by transmitting a false GPS signal is unlikely, because the signal is protected by a code which can easily be altered or encrypted. Spot jamming of user sets would be difficult since user sets are passive and the enemy would not normally be able to locate the user's position with direction-finding equipment. Even if the user's position were known, the enemy would be uncertain as to the effectiveness of his jamming attack. Jamming intended to degrade the monitor sets' reception of the satellites' signals is not anticipated because monitor sets will be located on United States territory.

There are two areas where jamming could effectively jeopardize GPS operation. In a very dense jamming environment, such as that encountered in central Europe, user reception of GPS signals could be degraded over large geographical areas. As a possible countermeasure, the GPS program office is considering the feasibility of supplementing the planned 24 satellite operational configuration with three stationary satellites over Europe. These additional satellites using focusing antennae could provide power levels 100 times greater than the other GPS satellites and thereby penetrate the European jamming environment.

The other areas where GPS operation could be impaired by electronic countermeasures concern the jamming of the upload station-to-satellite commands. These commands are required on a periodic basis since the system's accuracy

slowly degrades. Although no overt jamming of this type has been observed, there have been some cases in which U.S. space communications have been degraded by radio frequency interference of questionable origin. Program officials see no technological barriers to countering possible jamming of the uplink commands but have not yet explored this issue in any depth. They believe that this question can best be addressed in phase II after GPS has demonstrated its basic performance capabilities and after equipment configurations have been firmly defined.

CONCLUSIONS

The GPS program, as most major development programs, experienced technical development problems. Program officials believe the problems have been resolved; however, not all solutions have been thoroughly tested. System testing of GPS will not begin until mid-1977. The program office established goals for GPS, but many system performance requirements were not quantified. We noted that, in GPS field testing, the extent of performance demonstration is at the discretion of the Program Manager.

Phase I testing of the GPS will be based on project office interpretations of the needs of potential users of GPS. In our opinion, the services should formally present their requirements and the program office should be directing its actions to meeting officially sanctioned requirements. We are also of the view that concept validation criteria acceptable to both the program management and the authority approving future GPS development should be the basis of GPS field testing.

RECOMMENDATIONS

GAO recommends that the Secretary of Defense

--review the GPS program to determine the operational system performance required by the Air Force, Army, Navy, and Marine corps and

--establish testing criteria for evaluating the adequacy of the GPS development progress and the readiness of GPS to proceed into the next development phase.

CHAPTER 3

NAVSTAR GPS SCHEDULE STATUS

Since phase I approval in December 1973, the GPS program schedule has undergone several changes. Development delays occurred, but their impact was minimized by restructuring the program. In the process, time planned for field testing GPS was shortened from 22 to 14 months. Although delays occurred in phase I, a plan was recently approved to accelerate user equipment development and satellite procurements.

APPROVED VERSUS CURRENT PHASE I SCHEDULE

The December 1973 Development Concept Paper shows the approved phase I program and schedule planning estimates for the three phases. The program is evolutionary in that, after the required phase I events occur, a Defense Systems Acquisition Review Council decision to approve phase II will be made. Presumably, a similar situation exists for the transition from phase II to phase III. The completion of phase I is a determinative factor in the start of phase II and, possibly, other events in both phase II and phase III.

The development schedules of each of the three phase I segments (i.e., space, control, and users) were, for the most part, independent of schedule events in developing the other two segments during the early stages of phase I. The baseline schedule called for the three development efforts to merge during mid-1976 to permit segment-to-segment checkout leading to system testing before the planned Acquisition Council's review in March 1978. However, development problems arose which prevented the integration of the three segments as planned.

As mentioned in chapter 2, the most significant development problems experienced during phase I concerned the X set receiver and the satellite signal transmitter. Of these, the X set problems had the greatest impact on the schedule because the X set is needed for (1) verifying the satellite transmitter prior to satellite launch, (2) receiving signals once the satellites are deployed, (3) developing the control segment, because control and monitor stations have X sets as an integral component, and (4) developing other types of user equipment. As of December 1976 the delays caused by X set problems overshadowed most other delays.

The effect of development delays on events in the baseline phase I schedule is shown in table 3.

TABLE 3

Comparison of the Baseline Phase I Schedule Events with Current Estimates

Milestone	Baseline schedule	Current estimate (note a)	Delay (months)
Complete X set deliveries	August 1976	May 1977	9
Begin range operations	May 1976	March 1977	10
NTS-2 launch	September 1976	April 1977	7
Monitor sets ready	November 1976	April 1977	5
Master control and upload stations ready	February 1977	April 1977	2
NDS launches			
NDS 1	March 1977	May 1977	2
NDS 2	May 1977	July 1977	2
NDS 3	July 1977	August 1977	1
NDS 4	September 1977	October 1977	1
NDS 5	November 1977	December 1977	1
Begin user equipment field testing	May 1976	March 1977	10
Four-satellite operation	October 1977	December 1977	2
Begin user equipment performance evaluation tests	October 1977	January 1978	3
Acquisition Council's review phase II approval	March 1978	May 1978	2

a/As of December 1976.

Although scheduled X set deliveries will slip at least 9 months, the other scheduled events are not expected to slip on a one-for-one basis. The GPS program office restructured the phase I schedule to minimize the impact of schedule

slippages on the Acquisition Council's review date. In the restructuring, the time allotted for phase I field testing was compressed by 8 months.

The baseline schedule called for field tests at the range to begin in May 1976 and to last through completion of development test and evaluation in March 1978, a 22-month period. The current schedule shows planned field tests are to occur from March 1977 through May 1978, a period of 14 months.

GPS program representatives stated the scope of phase I field testing has not changed from that planned before the compression, although the number of months reserved for field testing has been compressed. They contend the addition of two satellites in phase I to support a Navy program provides increased daily test time, and the number of test hours available with four satellites in view is about the same as planned for the 22-month test program. The officials agreed the current schedule is optimistic in that it cannot absorb additional delays without a corresponding slippage in the planned Acquisition Council's review date. As pointed out in chapter 2, the phase I test plan (or the Development Concept Paper) does not specify minimum testing to validate the GPS concept.

CHANGES TO PHASE II AND PHASE III SCHEDULES

Due to the expected 2-month slippage in completing phase I, some planned phase II events also had 1- to 2-month delays, but program officials hope to have compensated for the phase I delays by the end of phase II. Moreover, in June 1976 the Secretary of Defense authorized the GPS program office to accelerate phase II and phase III activities. Changes to these activities would enable the system to achieve an intitial operational capability in December 1983 rather than August 1984, as initially planned. At one time, the feasibilities of initial operational capability in 1981 and in 1982 were also explored. Neither alternative was approved because unacceptably increased funding would have been required in fiscal years 1977 and 1978.

Air Force officials told us that subsequent to our field work, changes in funding the satellite procurements will result in the initial operational capability reverting to August 1984. We did not examine the reasons for these changes nor evaluate whether they would affect program cost.

Phases II and III user equipment development will be accelerated by issuing the requests for proposals to industry prior to the time the phases are approved by the Acquisition Review Council. By this means the program office plans to avoid the 6-month delay normally incurred after phase approval, to issue proposal requests, and to select contractors. The program office plans to advise contractors that contract awards will be contingent on the Acquisition Council's approval to continue the program as planned. According to the Program Manager, the accelerated program does not involve additional technical risk and time allotted for phase II, and phase III testing remains unchanged. Procurement plans for phase III satellites were also revised. Under the revision, phase III satellite procurement would be initiated before the planned Acquisition Council's review for phase III. An Air Force official told us the date for the Acquisition Council's review would be revised. The Program Manager said the planned changes are predicted to result in a $47.3 million development cost savings.

Table 4 shows the baseline and accelerated program schedule. A comparison of the accelerated schedule with the estimated phase I schedule (table 3) shows that proposal requests for phase II user equipment will be issued in November 1977, 2 months before the estimated January 1978 beginning of Phase I user equipment performance evaluation tests. Air Force officials believe they will have sufficient data based on the 8 months of field testing scheduled to occur before the Acquisition Council's review.

TABLE 4

Comparison of the Baseline and Current Program Schedule

	Baseline schedule	Current schedule
Phase I:		
Phase I approval	December 1973	
Issue phase II user equipment proposal requests (not including Z set)	July 1979	November 1977
Acquisition Council's review for beginning phase II	March 1978	May 1978
Phase II:		
Production contract award for Z sets	January 1979	January 1979
Phase II user equipment contract award	January 1979	June 1978
Begin Z set final operational testing	May 1980	May 1980
Begin field testing phase II user equipment	June 1980	March 1980
Begin operational master control and upload station operations	June 1981	June 1981
Issue phase III user equipment proposal requests	February 1982	August 1981
Limited operational capability (nine satellites: two-dimensional navigation)	June 1981	June 1981
Acquisition Council's review for beginning phase III	January 1982	January 1982
Phase III:		
Begin final operational testing of phase III user equipment	November 1983	March 1983
Initial Operational Capability (18 satellites: 3-dimensional capability)	August 1984	December 1983
24-satellite operation	August 1985	December 1984

CONCLUSIONS

The GPS phase I program schedule has been compressed to offset development delays. This schedule compression reduced the time allocated for phase I field testing from 22 to 14 months. In spite of program officials' assurances that the scope of phase I testing will be sufficient, we believe that the compressed testing schedule combined with the absence of minimum amount of testing required could result in a trade-off between complete phase I testing and further slippage in beginning phase II of the GPS program. User commitments to GPS are to be based primarily on the results of phase I testing. Since these decisions could have an impact on numerous other programs and systems and involve considerable cost to the Government (see p. 27), we believe the completeness of phase I testing is of great importance.

The Air Force plans to solicit proposals for phase II user equipment before performance evaluation testing of phase I user equipment concepts. On the basis of our examination of other programs which have resorted to forms of concurrency to save time, we question the efficacy of this procedure for accelerating the GPS program.

RECOMMENDATIONS

GAO recommends that the Secretary of Defense

--assess the time allotted for the GPS phase I test program relative to the scope of testing needed to demonstrate the GPS development progress and

--explore alternatives to the planned solicitation of contractor proposals before testing, as a means of saving time.

CHAPTER 4

NAVSTAR GPS PROGRAM COST STATUS

Since GPS phase I program approval in December 1973, the Office of the Secretary of Defense has directed numerous scope changes to the program. These changes have had a major impact on estimated program costs. This chapter describes the original and current approved program costs, the reasons for increased costs, the status relative to the approved program ceiling, and the cost effectiveness of GPS.

GPS PROGRAM BASELINE COST ESTIMATE

The cost estimate of $293.8 million for phase I of GPS has been approved. Costs for phases II and III were estimated primarily for planning purposes.

The total program cost estimate shown in the December 1973 Development Concept Paper, including Air Force, Navy, and Army funding, totaled $738.5 million. The following table shows the total estimated program cost by phase and by service in December 1973.

TABLE 5

GPS Program Baseline
Cost by Service, December 1973

	Phase I	Phase II	Phase III	Total
	----------(millions) (note a)----------			
Air Force	$128.4	$230.3	$332.9	$691.6
Navy	29.4	-	-	29.4
Army	17.5	-	-	17.5
Total	$175.3	$230.3	$332.9	$738.5

a/Then-year dollars.

Total program costs, by program segment and by phase, were allocated as shown in the following table.

TABLE 6

GPS Program Baseline
Cost by Program Segment, December 1973

	Phase I	Phase II	Phase III	Total
	----------(millions) (note a)----------			
Spacecraft	$ 84.0	$109.2	$190.5	$383.7
Control and user	40.2	53.7	96.2	190.1
Launch	27.1	40.4	20.3	87.8
Testing	12.3	13.0	20.6	45.9
Other	11.7	14.0	5.3	31.0
Total	$175.3	$230.3	$332.9	$738.5

a/Then-year dollars.

INCREASED PROGRAM COST

Estimated program costs have increased. For clarity, changes to approved program cost for phase I are discussed separately from the changes to the estimated costs for phases II and III.

Changes in phase I cost

The phase I cost estimate at the time of program approval totaled $175.3 million. Since that time, the approved program cost estimate was revised upward once. Total phase I cost is now estimated at $293.8 million.

A comparison of the current estimated cost with the baseline estimated cost for phase I is shown in the following table.

TABLE 7

Changes from Baseline Estimated Cost

to Current Estimated Cost for Phase I

	Baseline estimate December 1973	Current estimate December 1976	Change increase or decrease (-)
	(millions) (note a)		
Spacecraft	$ 84.0	$ 86.0	$ 2.0
Control and User	40.2	79.0	38.8
Launch	27.1	21.1	-6.0
Testing	12.3	15.1	2.8
Other	11.7	11.0	-.7
Support of the Navy's Fleet Ballistic Missile Improved Accuracy Program	-	75.7	75.7
NTS-2 launch responsibility	-	5.9	5.9
Total	$175.3	$293.8	$118.5

a/Then-year dollars.

The costs to support the Navy's Fleet Ballistic Missile Improved Accuracy Program and the assumption of NTS-2 launch costs by the GPS program were not part of the GPS baseline estimate. These additions have increased program cost by $75.7 million and $5.9 million, respectively. Also increasing the cost was about $14 million in cost overuns in user equipment development. The remaining increase was due primarily to the increased program scope, such as the alternate user equipment developments. (See p. 6.)

In addition to the cost increases shown above, other program-related activities were approved that were not considered part of the GPS development program. Cost for these activities was not included in the GPS program cost. Not included were costs for:

--Preliminary studies for the predecessor program to GPS, $9.5 million funded by the Air force.

--Specialized demonstration of user equipment by the Defense Mapping Agency, estimated at $0.2 million.

--Satellite tracking experiments by Defense Mapping Agency and National Aeronautics and Space Administration, estimated at $2.8 million.

--Secondary payloads for incorporation into GPS satellites, about $10.5 million.

--Atlas F launch services, beginning in fiscal year 1978, to be funded under the Space Booster Program (estimated amount not available).

Changes to costs in phases II and III

The following table compares the current estimates with the original planning estimates for phases II and III.

TABLE 8

	Baseline estimate December 1973	Current estimate December 1976	Change
	----------(millions) (note a)----------		
Phase II	$230.3	$ 477.2	$246.9
Phase III	331.9	552.0	220.1
Total	$562.2	$1,029.2	$467.0

a/Then-year dollars.

The estimated cost increases for phase II and phase III are attributed primarily to the anticipated cost growth in procurement cost for phase II and phase III satellites. Satellite costs have already shown major increases during phase I, a unit cost increase of $2.6 million for each satellite (unescalated fiscal year 1974 dollars). Program officials attribute the increases to high inflation factors and rapidly increasing costs in the satellite industry.

An important point about the cost shown in the above table is that, except for Army and Navy funding of $92.1 million in phase III, these estimates reflect the cost of Air Force participation only. Navy funding for phase II is currently being evaluated. Army and Navy involvement in phase II,

or new involvement by any other governmental agencies in any phase, would add to total program costs.

CURRENT PROGRAM COST ESTIMATES

Current estimates indicate that total GPS Phase I, II, and III costs could exceed $1,323.0 million, as follows:

	Estimated cost (million)
Phase I (from table 7)	$ 293.8
Phases II and III (from table 8)	1,029.2
Total	$1,323.0

The current program cost does not include all costs to have the GPS capability. Total costs are estimated at about $3.4 billion, which includes costs for the acquisition, installation, and operation of user equipment for an anticipated Defense user population numbering 27,000 ($1.7 billion) and the annual acquisition of four replenishment satellites needed to maintain an operational 24-satellite constellation ($44 million annually).

COST STATUS RELATIVE TO THE APPROVED COST CEILING

The cost ceiling for phase I is given as a lump sum in fiscal year 1974 dollars and cannot be reliably escalated by year. Therefore the dollar amounts in this section are necessarily shown in unescalated fiscal year 1974 dollars.

The baseline phase I ceiling was $150 million at which time estimated phase I costs were $148.2 million. Due to scope additions, the ceiling was increased to $160 million. Because of further scope additions, a second revision to $180 million has been submitted for approval. Presently, phase I estimated costs are $177.9 million, which exceeds the last approved revision to the ceiling ($160 million), but is within the ceiling awaiting approval ($180 million).

Program officials fully expect this approval because the full scope of additions were directed and approved. Assuming the revised $180 million ceiling will be approved, estimated phase I costs are below that ceiling by $2.1 million, stated in fiscal year 1974 dollars, or about $2.7 million in fiscal year 1978 dollars. There is, however, a high probability that the $180 million ceiling will be exceeded by the end

of phase I. Phase II and phase III cost ceilings have not been established but are to be established as those phases are approved.

POTENTIAL FOR EXCEEDING APPROVED PROGRAM COST

As previously noted, the user equipment development has experienced design problems, the corrective redesign measures have undergone only limited testing, and the remaining phase I schedule for field testing has been compressed to compensate for early phase I schedule slippage. Therefore further delays could easily occur and could have an impact on the planned phase I completion date and add to current phase I cost estimates. In addition to costs that could be incurred because of further schedule slippages, extra costs could be incurred to correct or replace malfunctioning GPS equipment or test support equipment, to conduct additional tests if test results are unsatisfactory, or for a variety of unforeseen phenomena inherent to the initial development process.

Another possibility that the projected ceiling of $180 million could be exceeded concerns the payment of incentive and award fees to the phase I contractors. Incentive and award payments of only $0.1 million are now included in the phase I budget and cost estimates, but as much as $12.2 million could be earned by the contractors. Although program officials doubt that the maximum fees will be paid, they agree that such fees could easily exceed the present margin of $2.7 million.

If the first five NDS satellites perform as planned, the satellite contractor would earn $5.7 million in performance incentives. For each satellite that fails to operate, as much as $0.9 million in negative incentives could be assessed, but there would be additional offsetting costs incurred for delays and, possibly, additional satellites. Provisions for phase I incentive and award fees are now being included in phase II estimates by the Air Force.

GPS COST EFFECTIVENESS

The Director of Defense Research and Engineering said in April 1975 that, based on design-to-cost goals, the GPS, when fully implemented, could achieve an annual cost saving of $200 million for Defense procurement of navigation systems. However, there are preliminary indications that such cost savings may not be achievable.

The design to cost goal of the "low cost" 2 set type of user equipment has not been achieved. Currently, 2 set costs are exceeding the goal by 15 percent. The cost status of other types of user equipment relative to the initial estimates used to project cost savings was not determined because the initial estimates were not available at the program office.

The increasing costs of the satellites is another indication that the initial estimate of cost savings resulting from GPS implementation may not be achievable. The expected cost increases for phase II and phase III satellite procurements were discussed previously. (See p. 28.)

SELECTED ACQUISITION REPORTING

The GPS, a joint service program, is not included in the Selected Acquisition Reporting System. Selected Acquisition Reports are standard, comprehensive, summary status reports on major defense systems. Due to the numerous interrelationships of GPS to other systems and programs and the large increases to program costs and scope, the inclusion of the GPS program in the Selected Acquisition Reporting System may be warranted for congressional visibility and Defense management purposes.

CONCLUSIONS

GPS estimated program cost has increased over 90 percent since program approval in December 1973. Current estimates now indicate that the total GPS program cost will exceed $1.3 billion and could increase further. Although the program development cost estimates were increased, they do not show all cost for GPS activity. Further, in our opinion, the total cost to have the GPS capability should receive greater visibility.

RECOMMENDATIONS

We recommends that the Secretary of Defense

--determine the total cost for GPS and related activities and the total estimated cost to provide a GPS operational capability for all the military services and

--assure GPS program visibility by including it in the Selected Acquisition Reporting System.